Abstract

The objective of this master's research is to establish a metrology measurement method applicable under cryogenic and vacuum conditions for low-temperature telescopes, such as the LiteBIRD mission. To achieve LiteBIRD's scientific goal, of observing the primordial B-modes in the cosmic microwave background with high-sensitivity, the telescope optics require high alignment accuracy in a low-temperature environment. Therefore, in pre-launch ground verification tests, it is essential to accurately identify the thermal contraction and deformation of the telescope structure under cryogenic and vacuum conditions inside a space chamber and to verify consistency with the design values.

However, inside a cryogenic vacuum chamber, it is difficult to directly apply conventional three-dimensional metrology methods and techniques that are commonly used under ambient conditions. Given this background, this research focuses on photogrammetry, which measures the three-dimensional shape of an object from images taken from multiple viewpoints. Although photogrammetry is widely used at room temperature and atmospheric pressure, its application to cryogenic and vacuum environments has been limited, and a systematic evaluation of the measurement accuracy under these conditions is required.

In this research, based on a commercial photogrammetry system (Hexagon AICON DPA; accuracy of 5 μm + 2 μm/m under ambient conditions), a photogrammetry system was developed to operate under cryogenic and vacuum conditions, targeting 50 μm (RMS) measurement accuracy. Demonstration tests were conducted in the National Institute for Fusion Science (NIFS) 2.6-m chamber and the Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), 4-m space chamber. In the 4-m space chamber, a LiteBIRD Low-Frequency Telescope half-scale model (900 × 700 × 600 mm) was measured, confirming that photogrammetry measurements can be successfully performed under cryogenic and vacuum conditions. By comparing measurement data acquired at room temperature and at cryogenic temperatures, the thermal contraction behavior of the half-scale mode was evaluated. In addition, the measurement error was evaluated using the residual after removing the uniform thermal component. As a result, an accuracy of 36.4 μm or less (3D RMS) was achieved under conditions where the chamber reached 100 K and the specimen temperature was ≤160 K. These results demonstrate that the developed system enables quantitative evaluation of thermal contraction and shape differences of telescope structures under cryogenic and vacuum conditions.